Pulldown Forces for Collecting Large Soil Monoliths

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ABSTRACT. *The force for pulling down large, steel monolith tanks was measured for a fine sandy loam, a silt loam, and clay loam soil with varying soil water contents in two of the soils. Pressure gages on hydraulic jacking equipment were used to measure force as a function of depth throughout the 2.4-m installation depth of the soil monolith tanks. Monolith tank areas were 0.75 × 1.00 m or 3.00 × 3.00 m, and the tank wall thickness was 9.5 mm. Except for the effects of natural hard pans or plow pans, pulldown force was linearly related to depth. When pulldown force was converted to wall friction, the average wall friction after wetting for each of the three soils was about 20 kPa. For most agricultural soils without rocks or cemented layers, the monolith tank wall friction from prewetted soil should also be less than 20 kPa. Wall friction variability decreased with depth so that a safety factor of 1.25 would be satisfactory in designing monolith collection equipment.* ***Keywords.*** *Monolith, Soil, force, Wall friction, Soil tank.*

Monolithic lysimeters are preferred over repacked lysimeters for both evapotranspiration and drainage research. For many soils, data collected with repacked or filled in lysimeters may not be reliable and representative of field conditions (Bergstrom, 1990). Several years of research data monitoring may be required before the soil water properties of a repacked lysimeter stabilize sufficiently to provide accurate evapotranspiration data (Grebet and Cuenca, 1991). The high cost of inaccurate data or of several years of trial operation can make research with repacked lysimeters more expensive than comparable research with monolithic lysimeters.

With modern construction practices and large machinery, soil monoliths can often be collected with less time and expense than repacking the soil in a similarly-sized tank. Researchers have utilized a number of new techniques for enclosing and undercutting soil monoliths (Schneider and Howell, 1991). Large cranes and backhoes, various types of hydraulic jacks, and deep anchors for jacking down monolith tanks are now routinely used in the collection of large monoliths. Similar advances have not been made in the procedures for repacking a lysimeter soil tank. The process remains one of carefully excavating, storing, and repacking soil layers, and then wetting and draining the soil to return the density to near the original value and to hopefully regain the original hydraulic properties.

Large soil monoliths are usually collected by forcing bottomless steel tanks into the soil and then undercutting the enclosed soil block at the desired depth. Both dead weights and hydraulic jacking equipment have been used to push the bottomless tanks into the soil. Some researchers have reported the total weight used in the collection of large monoliths (Dugas et al., 1985; Tackett et al., 1965). Other researchers have reported the size of the hydraulic jacking equipment (Belford, 1979; Meyer et al., 1985). To date there is no reported information about the force-depth relationships or wall friction values for collecting large soil monoliths.

This article presents hydraulic pulldown forces and wall friction values for collecting soil monoliths for two weighing lysimeter projects. Guidelines are presented for the amount of force needed to pull down monolith tanks and for designing the equipment needed to provide the pulldown force.

Procedure

Two sizes of soil monoliths were collected using the hydraulic pulldown procedure described by Schneider et al. (1988). In the first study, 3.00-m × 3.00-m × 2.4-m-deep steel monolith tanks were pulled down while the soil was excavated around the outside of the tanks (Marek et al., 1988 and Schneider et al., 1988). In the second study, 0.75-m × 1.0-m × 2.4-m-deep steel monolith tanks were pulled down without excavating around the outside of the tanks (Schneider et al., 1993). In this article, the monoliths with the 3.00-m × 3.00-m and 0.75-m × 1.00-m surface areas will be referred to as the large and small monoliths, respectively. The large monoliths were collected in Pullman clay loam soil which is a fine, mixed, thermic torrertic Paulestolls. The small monoliths were collected in the Pullman soil and also in Amarillo sandy loam, a loamy,

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mixed, thermic aridic Paliustalfs, and Ulysses silt loam, a fine-silty, mixed, mesic aridic Haplustolls.

Monolith Tank Design

Both the large and small monolith tanks were constructed of 9.5-mm steel plate, but the wall reinforcement and cutting edges were different. The large monolith tanks were reinforced on the outside with 76-mm standard I beams, thus requiring excavation as the tanks were pulled down. The walls of the small tanks were not reinforced. A simple 45° bevel cutting edge (fig. 1) was satisfactory for the large monolith tanks, but on the small tanks this cutting edge resulted in as much as 118 mm of monolith compression and excessively large pulldown forces (Schneider et al., 1993). The more complex design for the small tanks reduced the pulldown force, reduced the monolith compression to less than 1%, and equalized the bending forces on the tank walls. Although the small monoliths were 3 mm smaller in each direction than the enclosing tanks, tilling the surface soil has prevented preferential flow along the tank walls. The large tanks were painted with Rustoleum® epoxy primer and paint. For the small tanks, the inside walls were painted with a commercial grade enamel, and the outside walls were painted with a red lead primer.

Force Measurement

Pulldown forces were measured with high-pressure gages attached to individual hydraulic jacks. The faces of the Bourdon-type gages were scaled to indicate directly in force units for the various surface areas of the hydraulic pistons. Before collecting a group of monoliths, the four gages were simultaneously connected to a single jack to verify similar readings over the pressure range of the hydraulic system. Monolith tanks were pulled down in increments, and force readings were recorded at the end of each 0.3-m-depth increment. Soil friction was computed as the total force per unit surface area and expressed as kiloPascals (1 kPa = 1 kN/m^2).

Site Preparation

Site preparation consisted of soil wetting and in some instances chiseling or plowing to break up the compacted subsurface soil or plow pan. At the collection sites for the large monoliths, the soil was wetted by ponding water on the surface. At the collection sites for the small monoliths, the soil was wetted by placing water in the 0.6-m-diameter boreholes drilled for installing concrete anchors. The soil at the Amarillo sandy loam site was moldboard plowed to a 0.25 m depth, and for the Pullman clay loam monoliths collected in 1991, the soil was chiseled to a 0.30 m depth.

Soil water content was measured as a part of the procedure for collecting and preparing the monoliths for evapotranspiration studies. For the large monoliths, soil water was gravimetrically measured to verify that wetting had reached the bottom of the monolith collection zone. For the small monoliths, neutron access tubes were installed in the center of each monolith, and soil water was measured by the neutron attenuation method before the monoliths were removed from the ground. Volumetric soil water contents are designated as θ_a, the average water content of the soil monolith profile and are reported later.

To measure monolith compression three steel pins were driven into each monolith surface, and the pin elevations were surveyed before and after pulling down the monoliths. The pins were 7-mm-diameter × 155-mm-long nails with a 32-mm-diameter washer placed under the head of the nail. Pins were located at the center and along the 1.0-m centerline at a distance of 0.25 m from each wall.

Results

Pullman Soil Monoliths

Average pulldown forces as a function of depth for the small Pullman soil monoliths are illustrated in figure 2 for three soil water contents. For each data point, the vertical bar illustrates the range of force values, and N is the number of observations. In 1989 with $\theta_a = 0.26$, 14 monoliths were collected without soil wetting. In 1991 we attempted to collect six additional monoliths with $\theta_a =$

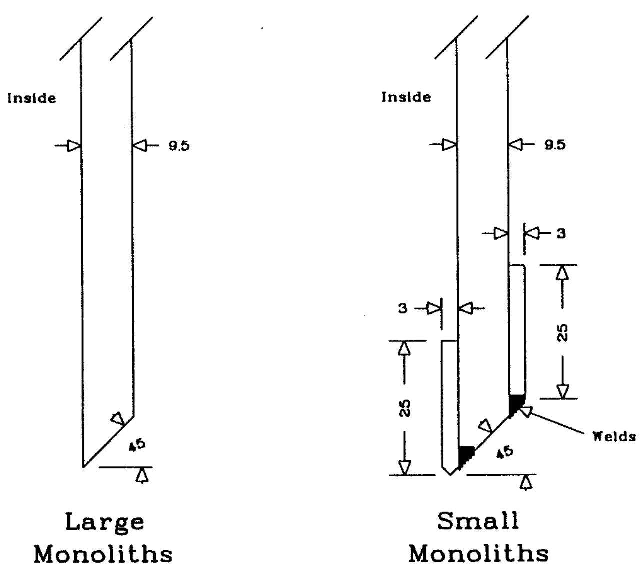

Figure 1–Cutting edges for soil monolith tanks (dimensions in mm).

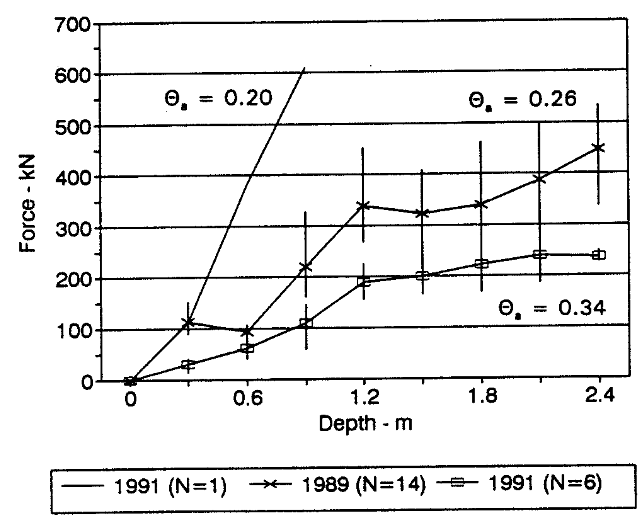

Figure 2–Average pulldown force for the small Pullman clay loam monoliths at Bushland, Tex., with N observations at soil water content (θ_a).

0.20. The pulldown force of the first monolith exceeded 600 kN, the maximum available with our equipment, at a depth of only 0.9 m. Before attempting to collect additional monoliths, we wetted the soil to $\theta_a = 0.34$, and the six monoliths were collected with an average force of only 240 kN at the 2.4 m depth.

The pulldown force data can be generalized by calculating the average wall friction as the monoliths are pulled down. The force data from figure 2 are illustrated as average wall friction in figure 3. For the two lower soil water contents, average wall friction was identical at the 0.3 m depth, but then diverged to quite different values. For $\theta_a = 0.26$, the average wall friction ranged from 20 to 40 kPa and converged to about 24 kPa at the three lower depths. In contrast, for $\theta_a = 0.20$, the average wall friction approached 100 kPa at the 0.9 m depth. When the soil was wetted to $\theta_a = 0.34$, the average wall friction reached a maximum value of 21 kPa at the 1.2 m depth, and then decreased slightly with increasing depth.

Average wall friction data for pulling down two large Pullman soil monoliths with $\theta_a = 0.30$ are illustrated in figure 4. The data are similar to the two groups of small Pullman monoliths with larger soil water contents. Average wall friction was nearly 40 kPa at the 0.3 m depth and then converged to about 20 kPa for the deeper depths.

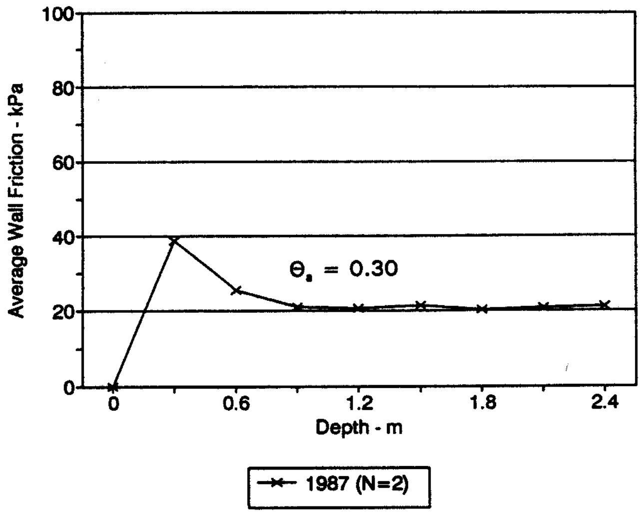

Figure 4–Average wall friction for the large Pullman clay loam monoliths at Bushland, Tex., with N observations at soil water content (θ_a).

Amarillo Soil Monoliths

The Amarillo soil monoliths were also collected at two soil water contents, and average wall friction values are illustrated in figure 5. A single monolith was pulled down with $\theta_a = 0.16$, and the average wall friction for the five lower depths ranged from 24 to 28 kPa (data were not collected for the three upper depths). Before additional monoliths were pulled down, runoff from a storm drained into the pier holes at the monolith collection site and wetted the entire soil profile. With $\theta_a = 0.18$, the average wall friction was approximately 20 kPa throughout the 2.4 m depth.

Ulysses Soil Monoliths

Average wall friction values for 25 Ulysses soil monoliths with $\theta_a = 0.18$ are illustrated in figure 6. Wall friction reached a maximum of 52 kPa at the 0.3 m depth, and then decreased to less than 20 kPa at the four deeper depths. The Ulysses soil was uniformly wetted from the boreholes before collecting the monoliths, and thus provided uniform wall friction values for the large number of monoliths collected.

Monolith Compression

With the cutting edge for the small monoliths illustrated in figure 1, compression of the 2.4-m-deep monoliths was usually less than 5 mm. Table 1 lists the average, minimum, and maximum monolith compression (average of three values) for the four groups of small monoliths. For the monoliths collected in all three soils in 1989, average

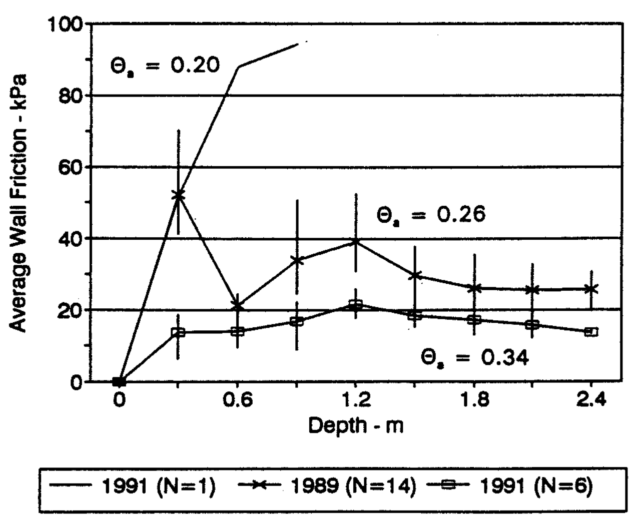

Figure 3–Average wall friction for the small Pullman clay loam monoliths at Bushland, Tex., with N observations at soil water content (θ_a).

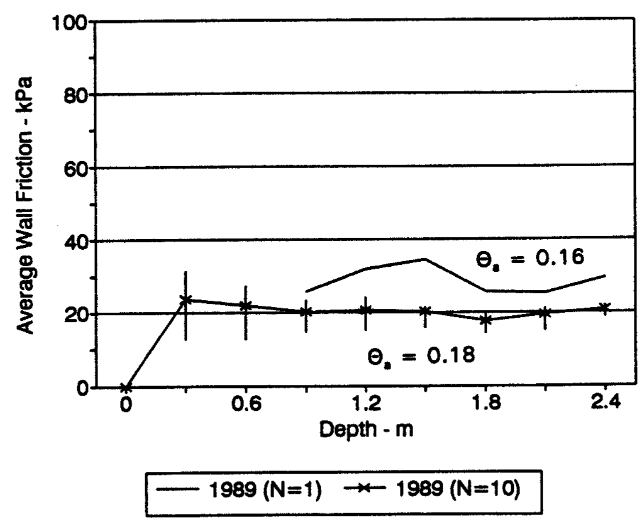

Figure 5–Average wall friction for the small Amarillo fine sandy loam monoliths at Big Spring, Tex., with N observations at soil water contents (θ_a).

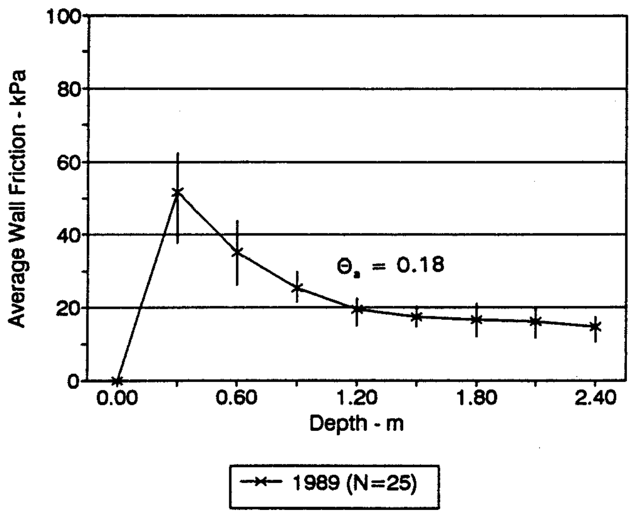

Figure 6–Average wall for the Ulysses silt loam monoliths at Garden City, Kans., with N observations at soil water content (θ_a).

monolith compression averaged 3 to 5 mm. For the Pullman soil monoliths collected with $\theta_a = 0.34$, however, average compression was 16 mm, and the maximum measured compression was 30 mm. Visual observations showed the corners of some monoliths to be compressed several millimeters more than the center, but there was no consistent pattern for the two outer survey pins to show more compression than the center pin. No soil compression measurements were made while collecting the two large monoliths.

Discussion

Soil preparation is the key to collection of large soil monoliths. Soil wetting can reduce wall friction several fold as illustrated by comparing the Pullman soil monoliths with $\theta_a = 0.20$ and $\theta_a = 0.34$. Even the small increase in θ_a from 0.16 to 0.18 for the Amarillo sandy loam soil resulted in the average wall friction being decreased as much as 50%. On tilled soils, wall friction can be reduced somewhat by deep plowing or chiseling to break up a plow pan or hardpan. Both the Pullman and Ulysses soils had a dense plow pan as illustrated by the largest average wall friction being measured at the 0.3 m depth. The site for the Pullman soil monoliths collected in 1991 was deep-chiseled before wetting, and the plow pan effect is absent.

Table 1. Average, minimum, and maximum compression of the small monoliths collected in the three soils

Soil	Year	Monoliths (No.)	Soil Water Content θ_a	Monolith Compression: Average (mm)	Minimum (mm)	Maximum (mm)
Pullman	1989	14	0.26	5	0	12
Pullman	1991	6	0.34	16	5	30
Amarillo	1989	10	0.18	3	0	7
Ulysses	1989	25	0.18	3	0	5

Soil tank preparation is also important in the collection of large soil monoliths. The tank surfaces need to be painted with a glossy finish paint both for reduced friction and for later corrosion protection. To further reduce wall friction of the small tanks we coated both sides of the walls with an inert, teflon-based dry lubricant. Surface coatings can be selected to enhance or inhibit microbial activity along the walls of the soil monolith and this feature needs to be considered in the paint selection. For collecting the small monoliths, we also developed the cutting edge illustrated in figure 1 to reduce the monolith compression and pulldown force.

Compression of the soil in the monoliths was not believed to be large enough to alter the soil properties. Average monolith compression for most of the monoliths was 5 mm or less which is less than 0.2% of the 2.4-m monolith depth. For the Pullman soil monoliths wetted to $\theta_a = 0.34$, however, average monolith compression was 16 mm (0.70%), and the maximum single monolith compression measured was 30 mm (1.25%). This illustrates that a minimum soil strength is needed during the collection of the soil monoliths. We have not noted any difference in physical properties or plant growth between the 14 Pullman soil monoliths collected in 1989 ($\theta_a = 0.26$) and the six collected in 1991 ($\theta_a = 0.34$).

By wetting the soil, the average wall friction was reduced to 20 kPa or less for each of the three soils. This value was obtained without reducing the soil strength to a level that soil compression was serious during the monolith collection process. The three soils in which the monoliths were collected represent a wide textural range of agricultural soils. Thus, the 20 kPa average wall friction appears to be a good design criterion for the maximum wall friction of most prewetted agricultural soils. The maximum wall friction values in the graphs provide guidelines for equipment design. The largest range in average wall friction was for the small Pullman soil monoliths collected in 1991. For these monoliths, maximum friction values were 1.25 to 1.5 times as large as the averages. For the other three groups of monoliths, maximum friction values did not exceed 1.3 times the averages. For all three soils, the ratio of maximum to average wall friction decreased with depth to a ratio no larger than 1.25. Larger variability at the shallower depths is not as critical because weights or pulldown equipment are not likely to be used to their maximum capacity at shallower depths.

A generalized procedure for using the data presented here to design pulldown equipment or deadweights will be illustrated with an example. Consider a 2-m-square monolith tank with a 1.5 m depth that is reinforced on the outside. The reinforcement will require excavation outside the tank so only the inside wall friction need be considered in the design calculations. The inside area of the tank is 12 m^2 (2 m × 1.5 m × 4 walls). Use the generalized wall friction value of 20 kPa to calculate an estimated maximum force of 240 kN (20 kPa × 12 m^2) for forcing the monolith into the soil. The maximum force can be adjusted with a safety factor of 1.25 to provide a maximum pulldown force of 300 kN or a maximum deadweight mass of 30.6 Mg. If the monolith tank walls were nonreinforced and the tank was pulled down without excavation, the wall area and thus the maximum pulldown force would be doubled.

Conclusions

For three soils that were wetted to reduce soil strength, the average wall friction on painted steel monolith tanks was 20 kPa or less. The variability of the average wall friction decreased with increasing depth so that a safety factor of 1.25 would be satisfactory in designing the monolith collection equipment. Since the three soils represent a wide textural range of agricultural soils, these values appear to be good guidelines for the collection of most large soil monoliths.

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